University of North Carolina at Chapel Hill

Detection of Possible Bolide Signals in Wanaka Balloon Data by Programming in R

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Abstract

A super pressure scientific balloon was set off by NASA in Wanaka, New Zealand on May 16th 2016, and the balloon floated for a record mid-latitude flight of 46 days, 20 hours, and 19 minutes. The seismology research group in UNC led by Dr. Jonathan M Lees set an array of three acoustic microphones on the balloon to collect the infrasonic signals at the altitude of around 30-40 km. After the data was retrieved, the wave forms were then selected with certain methods and some statistical analysis were then applied to figure out the possible events such as bolide explosions that could correspond to certain distinct wave form.

Introduction & Background

Bolides are large meteors that explode in the atmosphere before reaching the Earth surface. Some of the largest bolide events are captured and recorded by the NASA ground stations. From the NASA fire balls and bolide data site, 56 worldwide events that have energy above 1e+10 J have been recorded since 01/02/2016. In the 613 Julian days of record, the frequency of events is 0.093 event per day (November 25, 2017, Retrieved from https://cneos.jpl.nasa.gov/fireballs/.). From a past research on optical observations of bolides in Southern Ontario, Canada, 6989 meteor events were detected by the Southern Ontario Meteor Network (SOMN) (Weryk et al., 2007; Brown et al., 2010) between 2006 and 2011. Within the 2190 Julian days of record, the frequency of meteor is around 3.19 per day. By contrasting the two sets of data, it is not difficult to find out that the NASA ground stations have missed a large number of small scale bolide events. Our devices deployed on a balloon at 30 km to 40km in the atmosphere, and it went around the Antarctica for over 46 days, during which 14 days of infrasound data have been recorded. The high altitude devices has great advantages over the ground stations in that the devices are much closer to the sources of explosions and at that elevation in the sky, there are much fewer sound distractions. Although most undetected small scale bolides have limited hazards to human lives, they may have other potential destruction to human activities in the sky such as airplanes, upper air scientific devices, and the debris of explosions may eventually land on the ground causing damages to proprieties. The main object of my research is to look for bolide signals from the infrasound signals collected by our devices on the balloon. From the 14 days of acoustic data, 29 possible bolides signals were found by the computer program I wrote. The frequency of events is around 2.07 per day, which is close to the regional event frequency recorded by SOMN (Weryk et al., 2007; Brown et al., 2010). If the bolides detected by infrasound are proved to be real, then the next steps will be looking for the pattern of events and hopefully, a model of incoming bolide events will be constructed.

Data

A super pressure balloon is a kind of aerostatic balloon that can fly at a steady altitude for a long period, because the volume of the balloon is kept constant by controlling the lifting gas at same temperature. One of NASA super pressure balloon was set off in Wanaka, New Zealand on May 16th 2016, and the balloon floated for a record mid-latitude flight of 46 days, 20 hours, and 19 minutes. During the 14-day flight, the balloon flew around the Antarctica and passed by South America and Australia (figure 1).

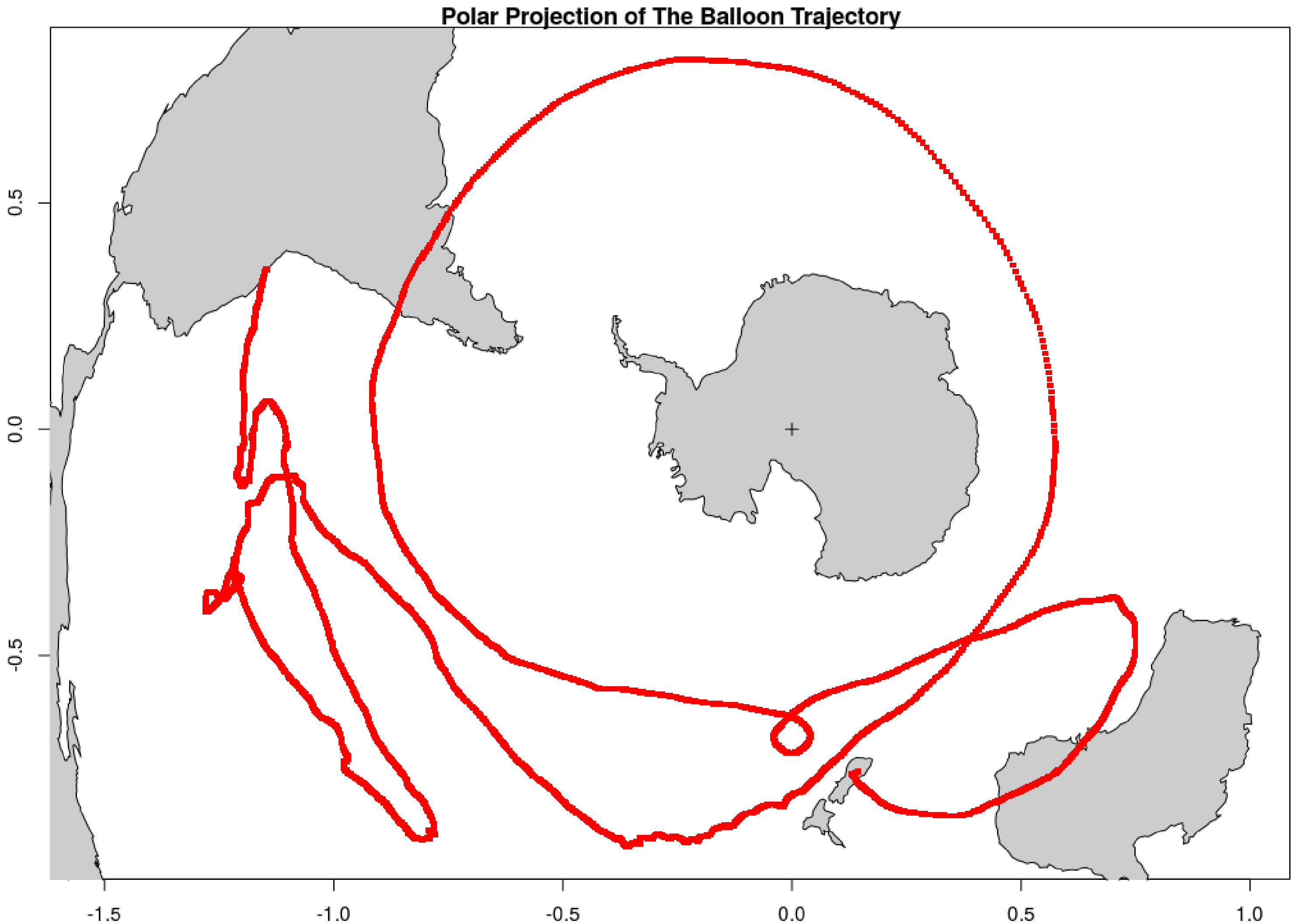


Figure 1: Red path is the trajectory of the balloon around Antarctica. Infrasound signals are recorded along only part of the path due to the limited battery capacity.

The purpose of this kind of balloon flights is to offer low-cost, near-space access for scientists and students to conduct their investigations. Our group set an array of three high sensitive acoustic microphones were set on the balloon. The microphones were juxtaposed with two of them recording air pressure signal, and the last one is an open channel which should not record any pressure signal. One of the pressure signal recording microphone has reversed polarity, so that when we subtract the second channel from the first one, the real signal is doubled and the noises will be reduced. The open channel microphone records no pressure signal, so anything recorded by the open channel should only be electric noises. Due to the fact that the two microphones are too close to each other, and there was no compass setup with our instruments, the orientation of the microphones is unable to be determined, so the back azimuth of infrasonic signals is unknown. The recording began on May 20 and stopped on June 2 after the device battery ran out. The sampling rate of the data base is 200 data points per second, and each data point records the pressure information with unit in volts (Since it is not intuitive to use volts as unit of sound magnitude, all the plots will not show unit on the y-axis).

One minor disadvantage of the super pressure balloon is that the flying direction was not in control. The balloon went in the direction that wind current brought it to. Although the balloon was floating without control, there are still some events expected to be seen in the data. First of all are the bolides impacts. Impacts that are influential have been reported and recorded by NASA ground monitoring stations, but those burned out before falling deep into atmosphere may only be recorded by station at high altitude. There are also other events like volcano eruption and mining blasts, or storms that produce powerful infrasonic signals, could be seen in the data.

Analysis

The raw data is not ready for processing, because the raw data contains too much unwanted information such as the daily trend of air pressure change (figure 2). The 5-day data in figure 2 is a clear illustration of very low frequency events. The pressure difference between days and nights are obvious.

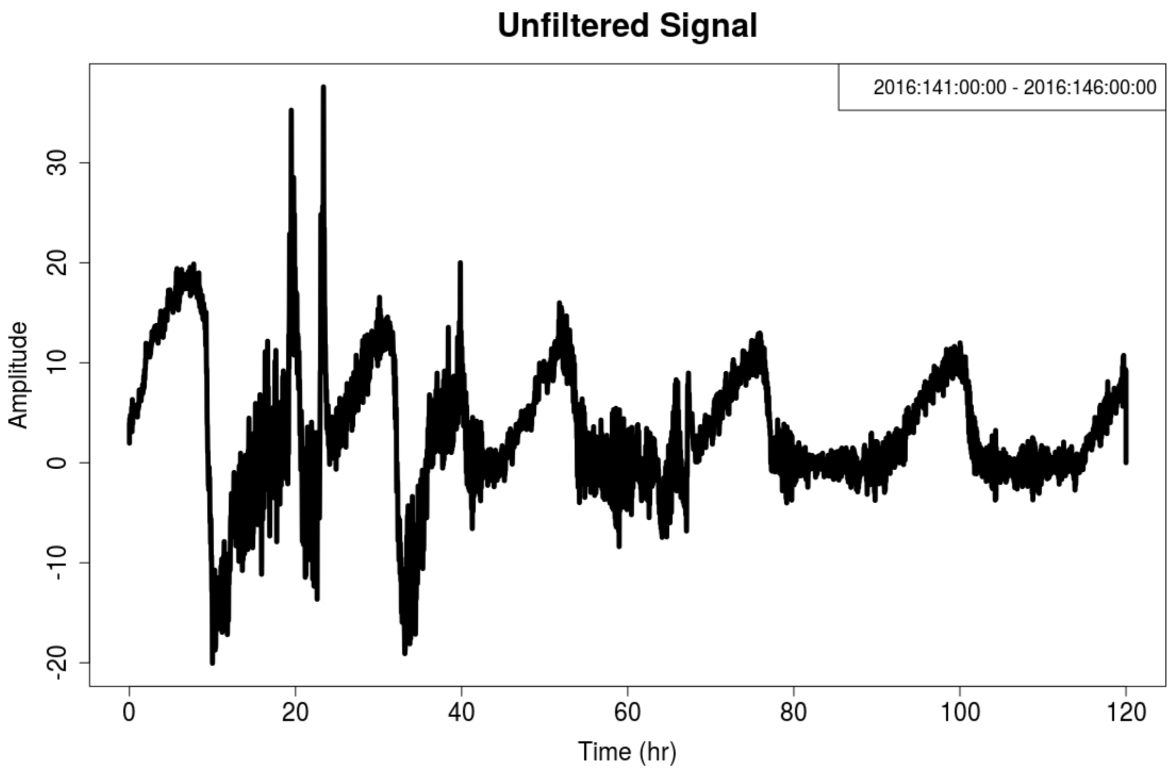


Figure 2: Periods of 12 and 24 hours are clear to observe in the data.

As the sun radiation heating up Earth atmosphere, the air pressure will gently increase during day time and decrease during the night. And since the balloon was not staying at the exactly the same altitude all the time, the air pressure environment was changing all the time. If we do the Fourier analysis of a 5-data as example, we will find a very strong low frequency signal in the spectrum (figure 3).

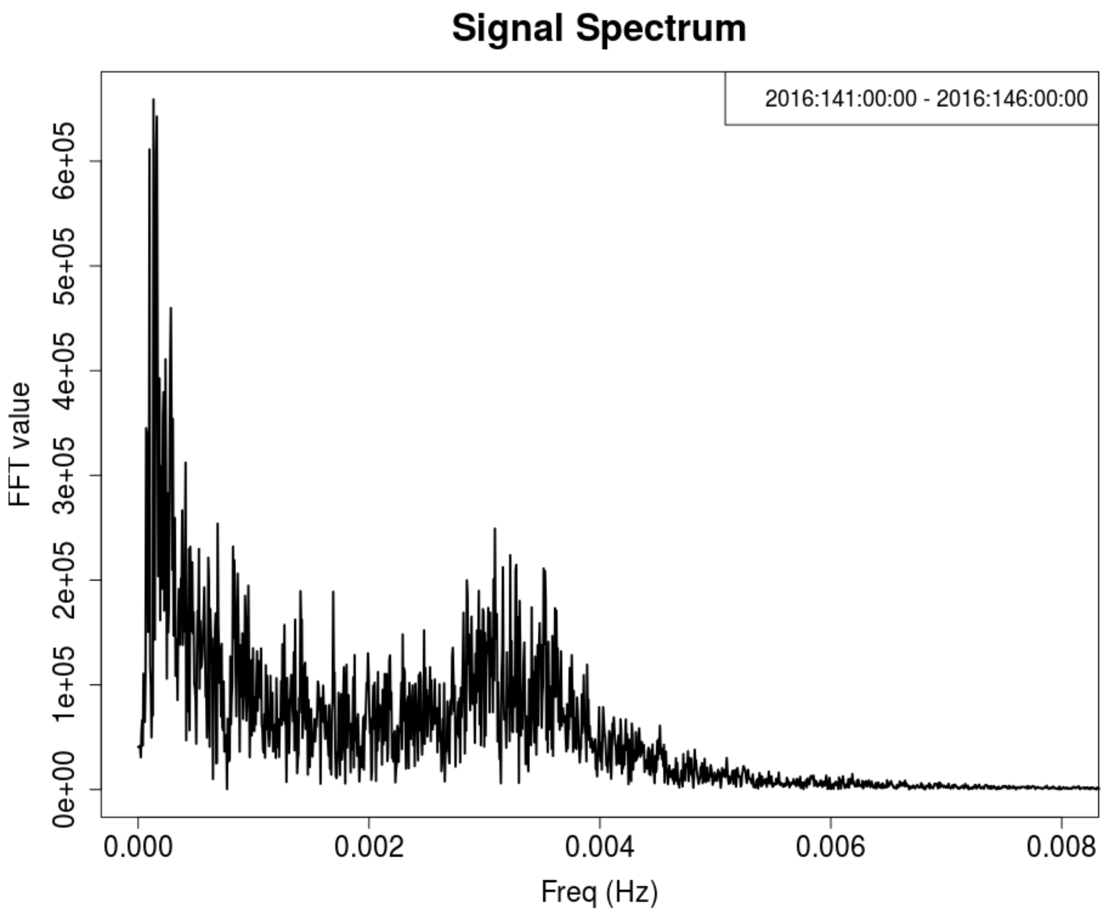


Figure 3: The dominant frequency is very low as shown in the spectrum.

We first apply a high pass filter (HP 1 Hz) to eliminate the low frequency trends. The resulted spectrum is as following (figure 4).

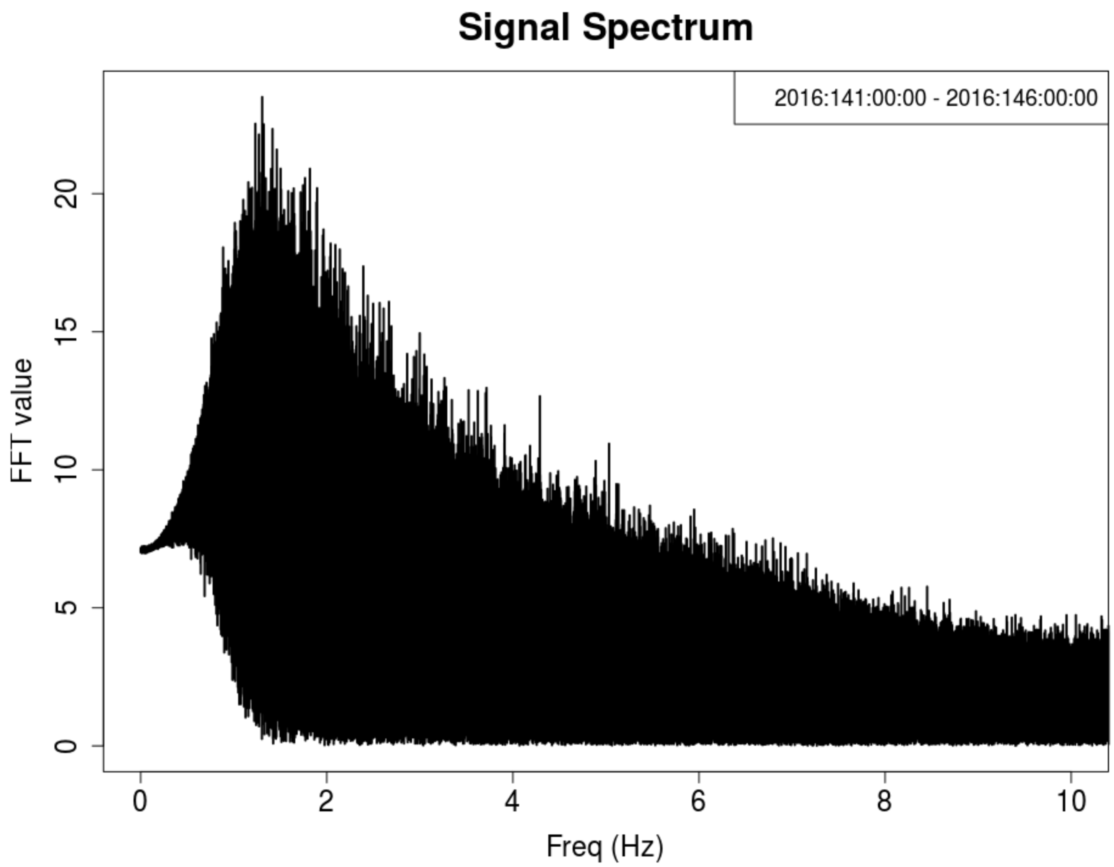


Figure 4: Spectrum after High Pass filtering. Note the edge effects caused by tapering at around 1 Hz.

There are still much high frequency signals recorded such as the wind and airplane noises. To have better analysis of the signal, we need to apply another low pass filter (LP 10 Hz) to the data (figure 5).

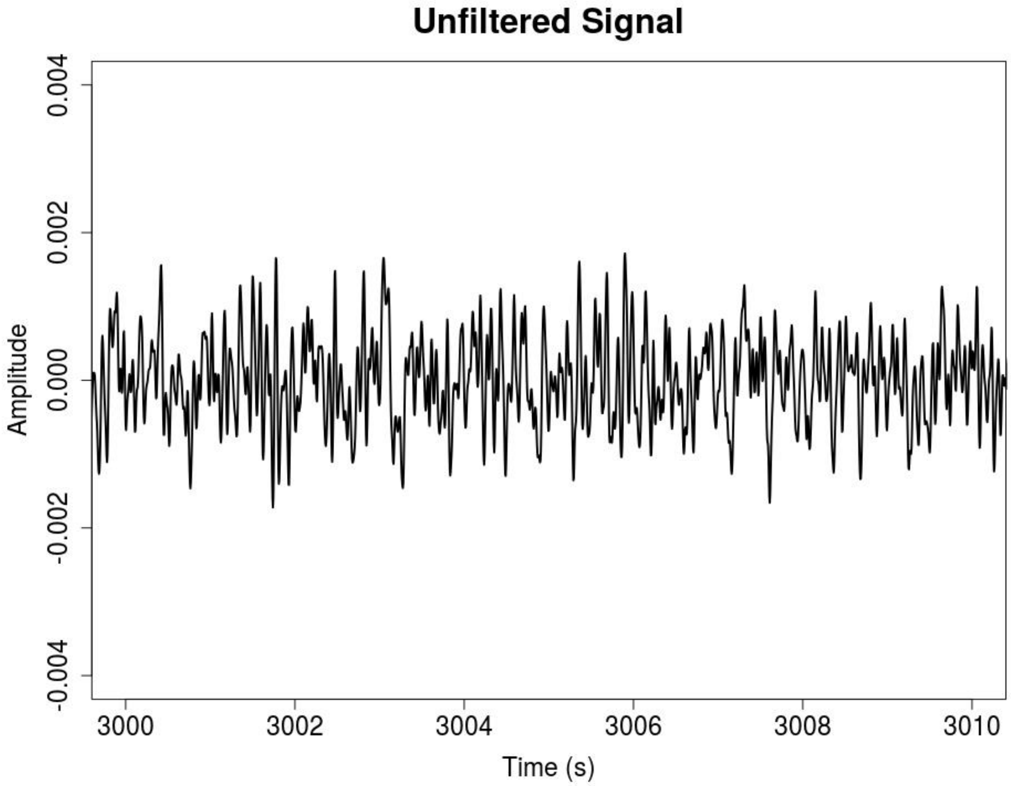


Figure 5: Time series before filtering out high frequencies.

Now the signals are filtered with band pass 1-10 Hz which may contain the bolide signals we are looking for.

As we learned from past research, an acoustic wave form that has a single or double high frequency and low time duration spike could be a possible bolide signal (figure 6) (Bowman & Roses, 2017).

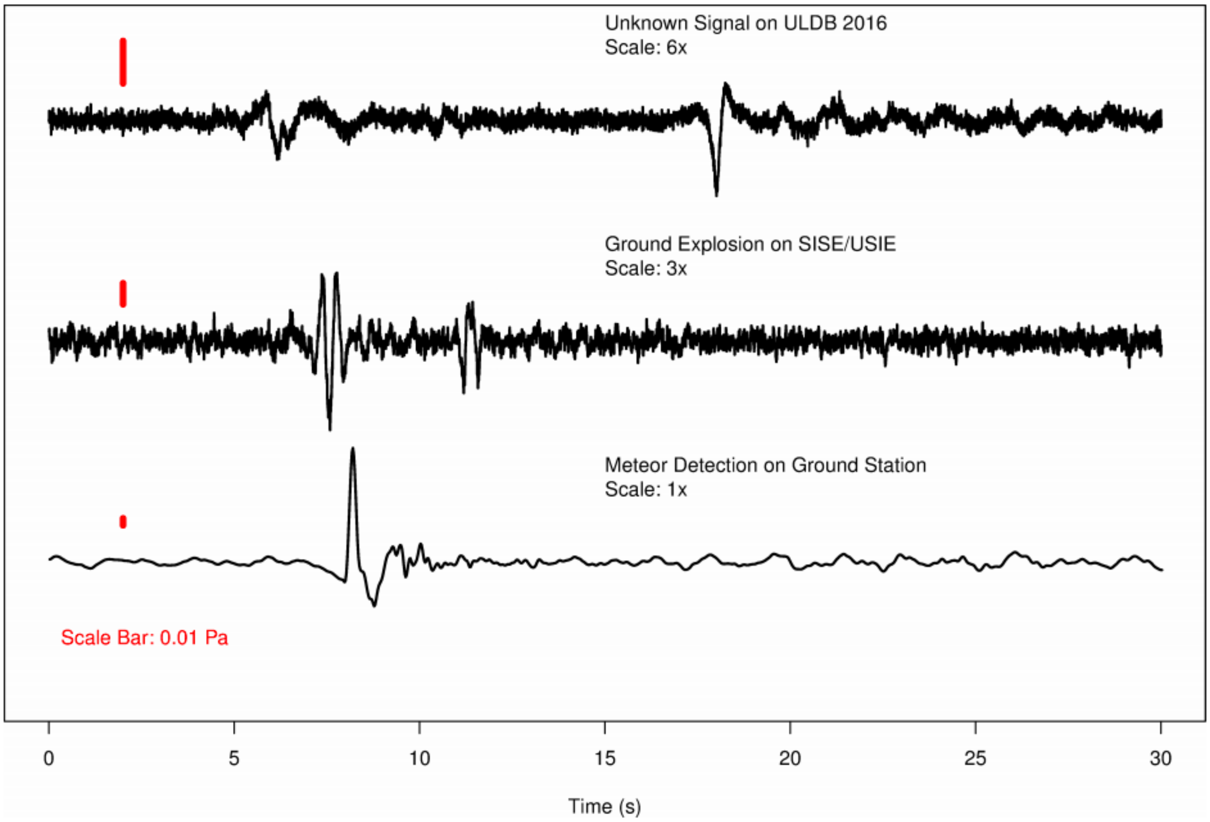


Figure 6: Infrasound from a meteor detected in southern New Mexico on March 23, 2017 (bottom), a 1000 kg TNT equivalent explosion recorded at a range of 330 km on a microphone at 34 km elevation (center) and a yet-unknown acoustic signal recorded 1700 km southwest of New Zealand on a microphone aboard the 2016 NASA Ultra Long Duration Balloon (top). (Bowman & Roses, 2017).

An R program is constructed to automatically select the similar bolide wave form from the data base. First of all, an algorithm that will sift out those high energy signals that have high amplitudes is applied. After that the program constructs 10-minute data windows and combines every 20 data points, which is 0.1 second length of data within every window. The sampling rate of the original data is 200 samples/second, and after down sampling, there are only 10 samples left in each second. The program then multiplies the mean with the standard deviation of the 20 data points and creates a new time series that have amplified signal to noise ratio (function 1):

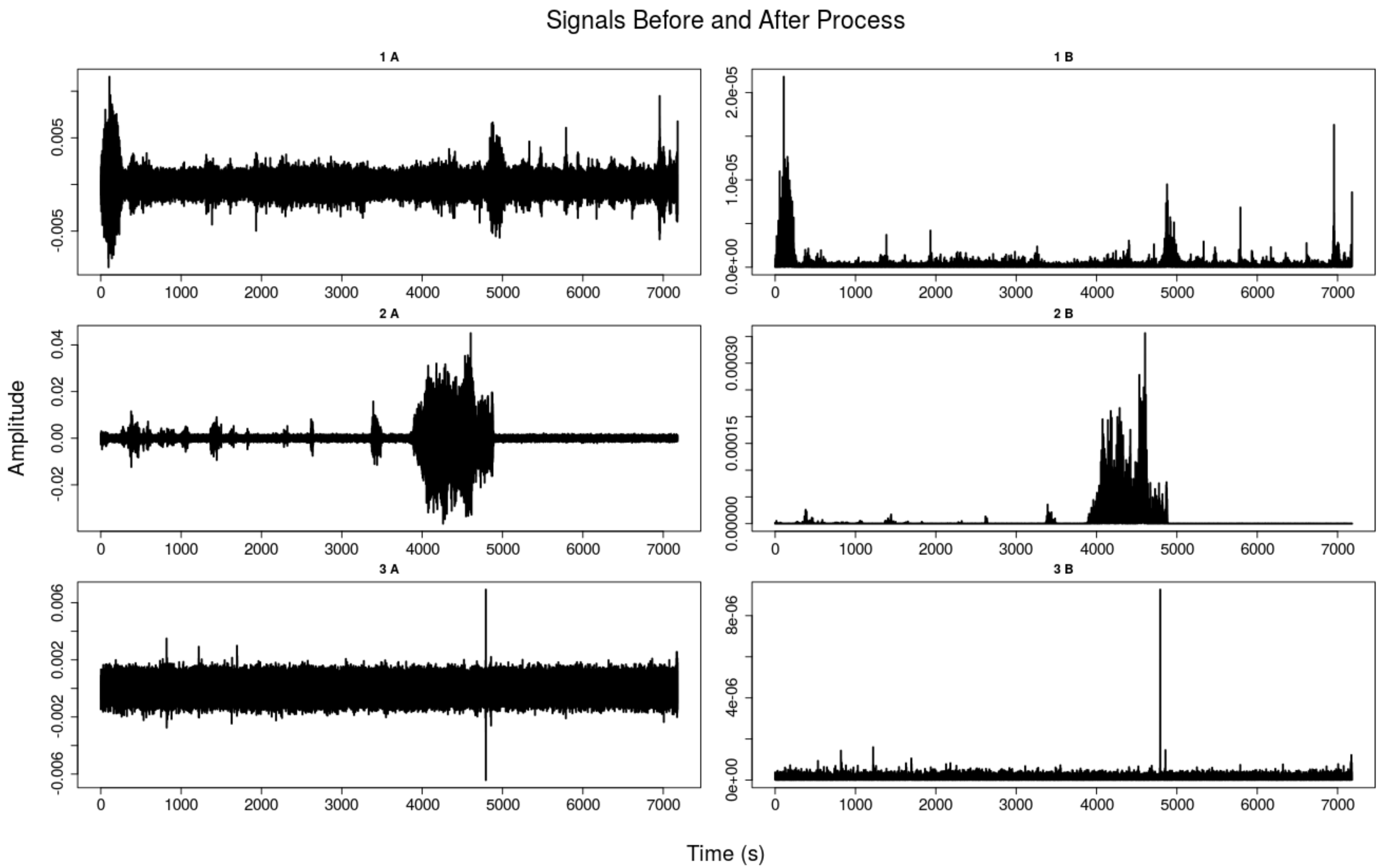


Figure 7: The original signals are on the left, and the processed signals are on the right.

$$En = \frac{\left(\sum_{i=1}^{20}|A_i|\right)}{20} \times \sigma_A$$

Function 1

The σ_A is the standard deviation of data points, which is an indication of the energy of the signal (higher standard deviation indicates that the residuals of data points are large and the amplitude of the signal changes in large scale). The 'En' is introduced to scale the energy of signals by the mean of absolute value of amplitudes. Figure 7 are samples of signals before and after processed by the algorithm.

The spike signal is amplified while the background noises are reduced. Then it is easier and faster to select out the high amplitude signals that we are interested in. The spike signal in plot 3A, figure 7 at around 4800 second is one of the possible bolide signals we are interested in. Following is a closer look of the signal:

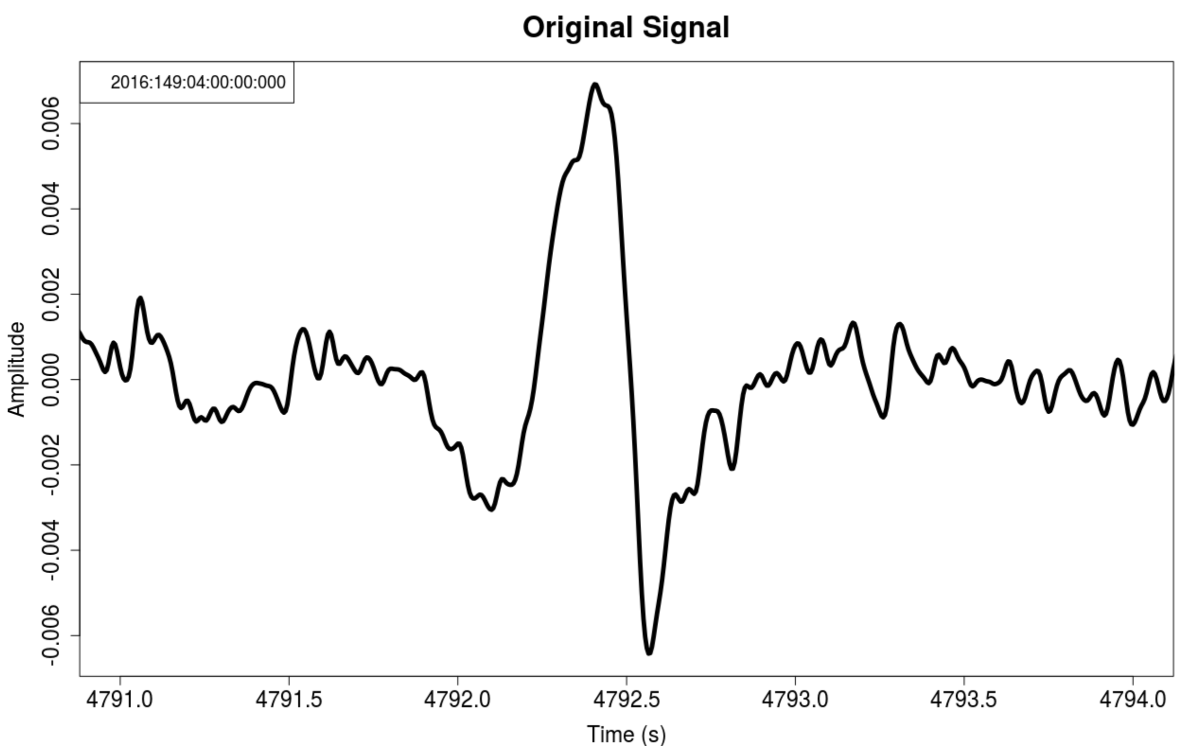


Figure 8: The spike signal has the shape similar to the bolide signals in the past research (figure 6).

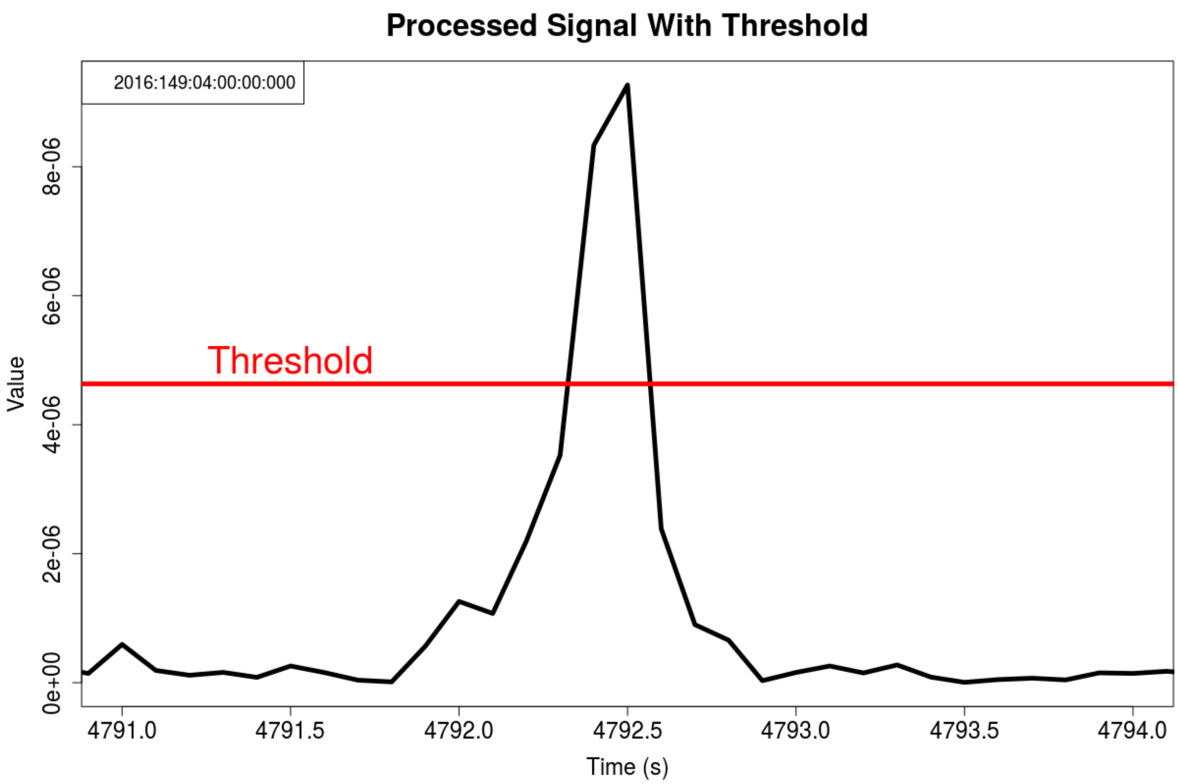


Figure 9: Signals that has En value higher than the threshold will pass the first step of selection and are saved for further selections.

Multiple thresholds of picking signal were tested, and the horizontal red line in figure 9, which indicates 50 percent of the highest En value is the lower limit, was the best one. If the threshold is set to more than 50 percent of highest En, some of the low energy signals won't pass the test, and if the threshold is set to less than 35 percent, too many signals with high energy but not in a spike form will be selected. Threshold between 35 percent and 50 percent all have the same results, while 50 percent threshold will significantly reduce the amount of calculation in the later processes.

The threshold value is highly sensitive to the program window size. Too small window size will significantly increase the number unwanted signals that pass through the first step of selection. A too large window size will miss low amplitude signals. For example, in figure 10 & 11, the signal at 4130 second is clearly a potential bolide signal, however in the two-hour window it has relatively low amplitude so it’s blocked by the large threshold value.

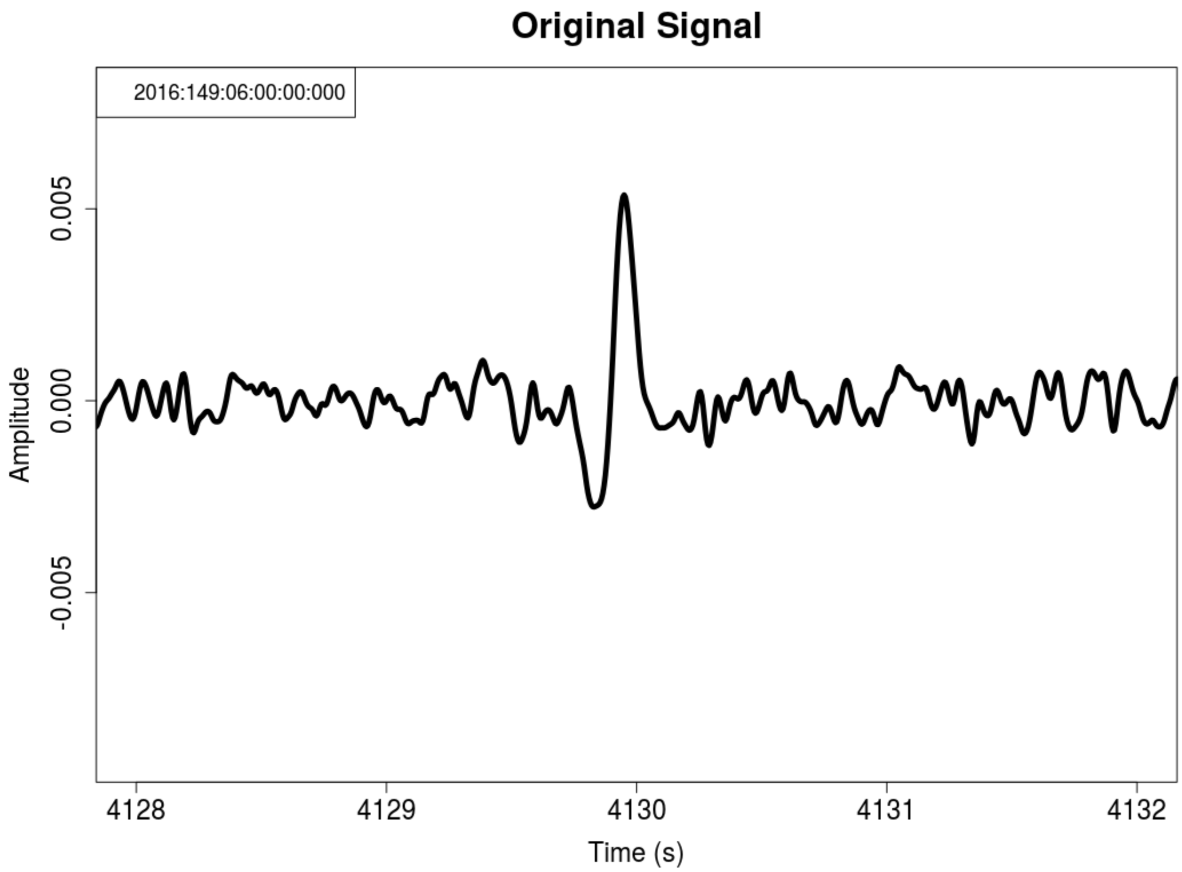


Figure 10: Possible bolide signal.

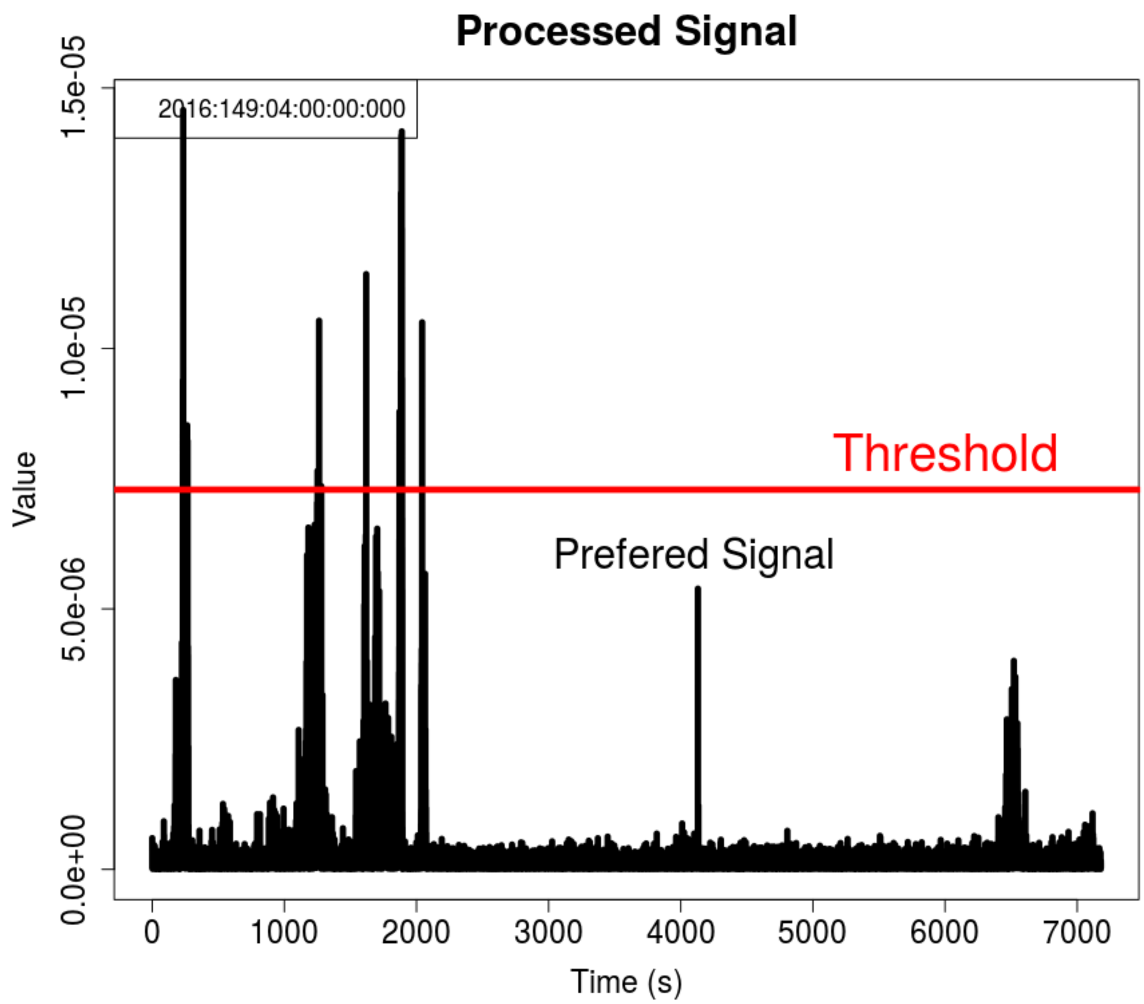


Figure 11: The possible signal has relatively low amplitude in the two-hour time series.

The selected signals contain not only the short time duration spikes, all the other high amplitude and long duration signals are also included (such as the huge chunk of signal between 4000s and 5000s in figure 7, plot 2A). Another program is then constructed to find out those signals with only single or double spikes and with much greater amplitude than their environments. The figure below are two examples from all the 29 signals that have passed the program selection (figure 12&13). The collection of all the possible bolide signals can be found in the **Appendix**.

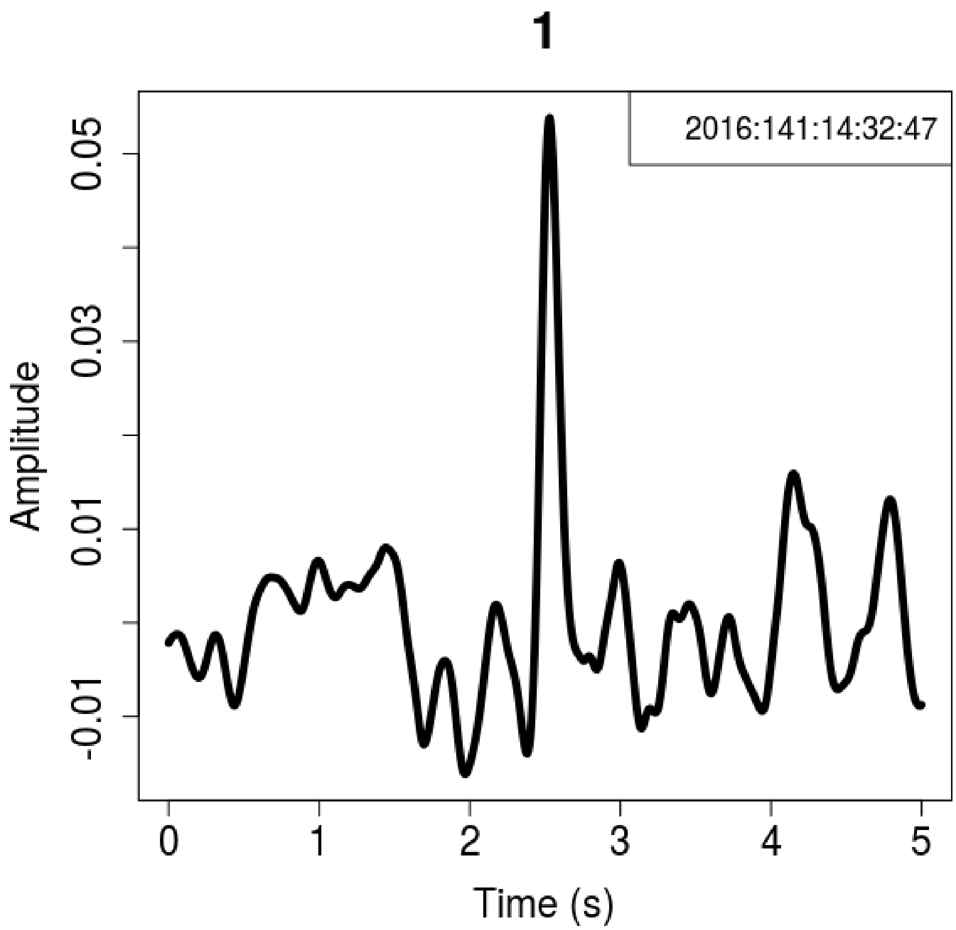


Figure 12: The legend box on the top right illustrates the exact time of peak, in the format:

Year:JulianDay:Hour:Minute:Second.

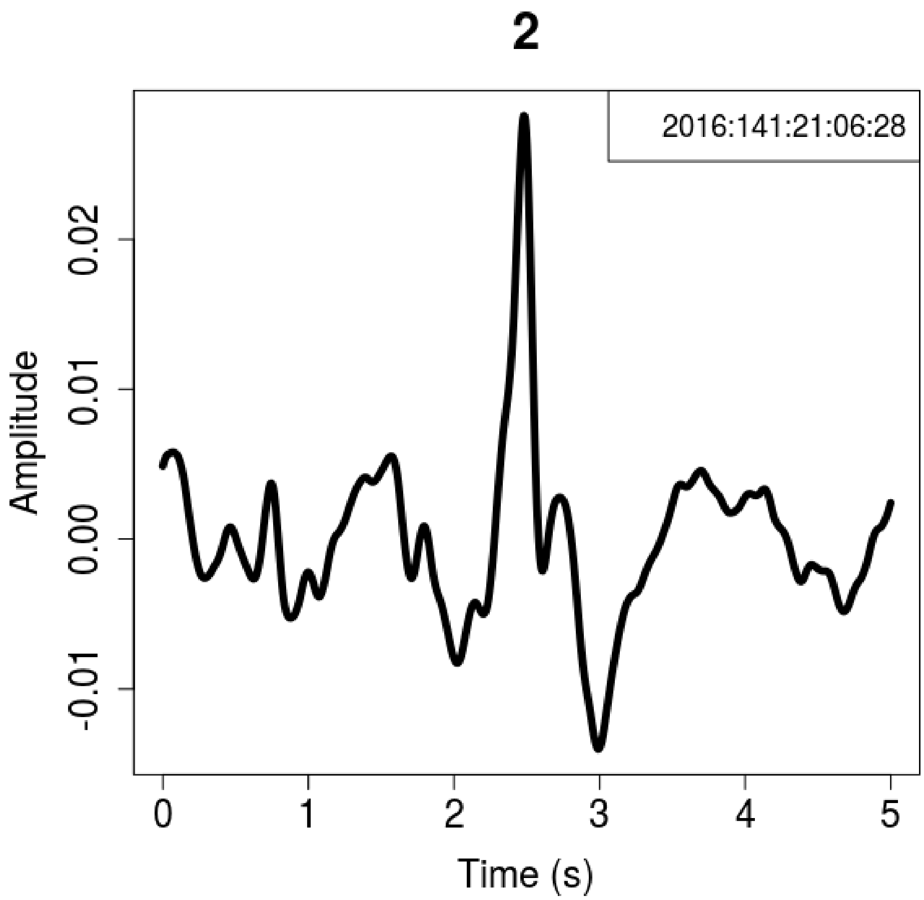


Figure 13.

The spikes are at the center of the plot, which contains much more energy than its environment signals. This kind of signals could represent an instant explosion which bursts spike signals, and an explosion at elevation of around 40 km is highly possible to be a bolide explosion.

The program successfully found multiple wave forms that could possibly be bolide signals. In order to check if any other possible signals are missed, the window size of 5, 15 and 30 minutes were applied in separate runs.

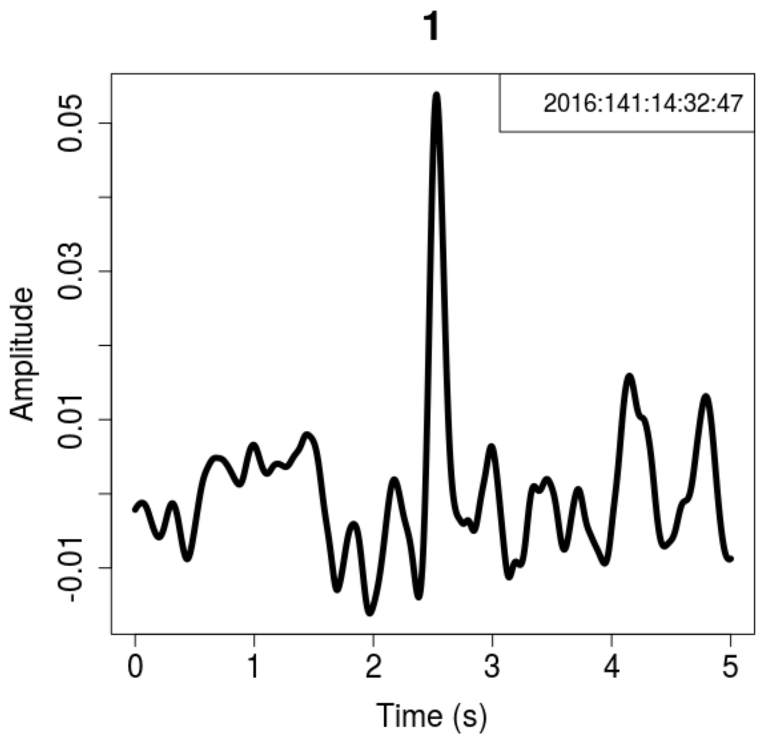
Discussion & Conclusion

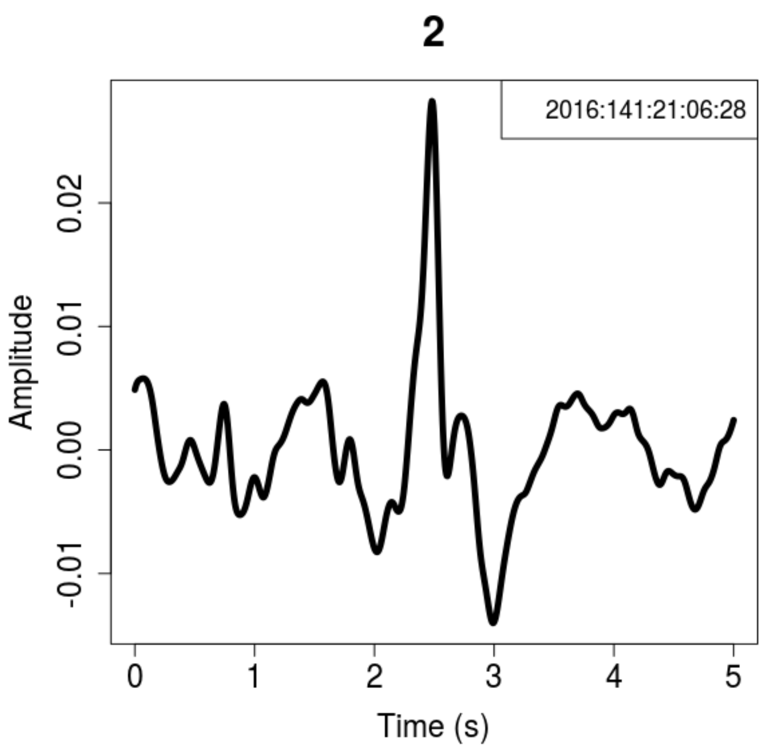
The possible bolide signals found all share the similarity that they all contain a strong spike which has much larger amplitude than the environment noises, and they cope with the infrasonic wave form discussed in the past research (Bowman & Roses, 2017). However, there is a speculation that the spikes could be electronic signals caused by cosmic rays. To solve this problem, we checked in the raw data whether the same spike has reversed polarity in the first two channels, since if it is electric signal, the polarity will be the same. Also, we checked the open channel. If the spike is not recorded by the open channel, then it is proved to be air pressure signal. After applying the two methods of verification, all the 29 possible bolide signals are proved not caused by cosmic rays.

It is very difficult to further prove the authenticity of the detected signals. The incoming azimuth is unknown and there is no other evidence of detection. Some of the signals may appear on the ground stations if they are detected when the balloon is above the land masses. However, none of the correlation between ground station data and balloon data succeed. It is highly possible that the 29 signals are either caused by events occur at very high altitude that are hardly detected by ground stations or they are simply signal shape noise with high amplitudes.

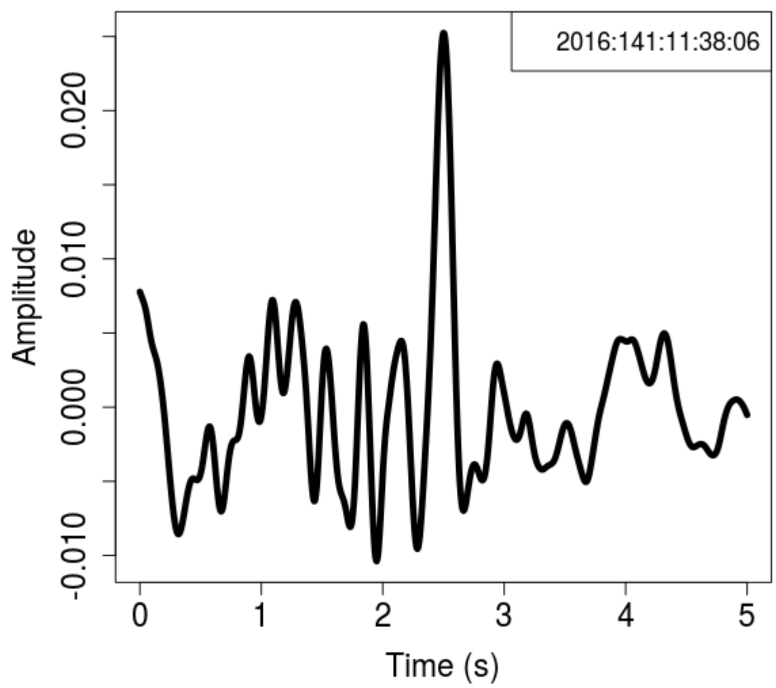
If all the bolide signals found by the method are later proved to be real, then we can prove the feasibility of detecting small scale explosion events by upper air infrasonic microphones. Other than bolides, we can also try to find other signals such as such as volcano eruption, military bomb explosion or mining. Hopefully in the future, similar method can be applied to larger data sets such as a three-month infrasound data from another balloon. With enough number of events, we can discover patterns of bolide events by looking for when and why does the events cluster, then a model can be created and even prediction of bolide events can be achieved.

Appendix: Collection of All Possible Bolide Signals





3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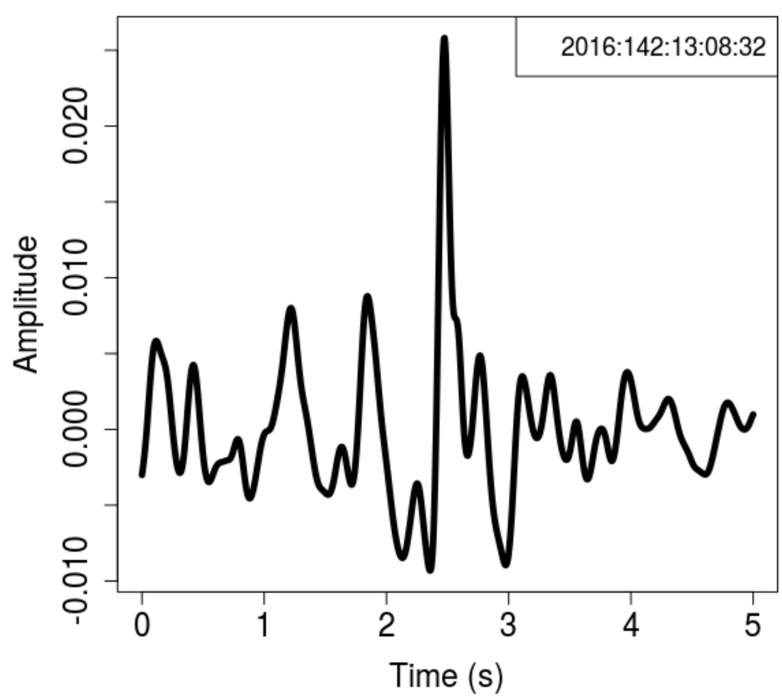
0.000
-0.010
0
1
2
3
4
5
Time (s)

4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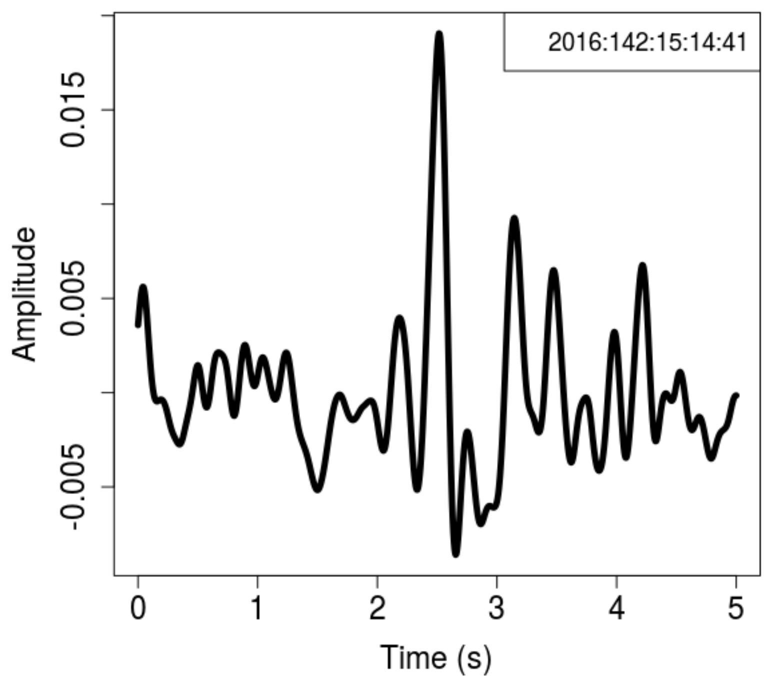
2
3
4
5
Time (s)

5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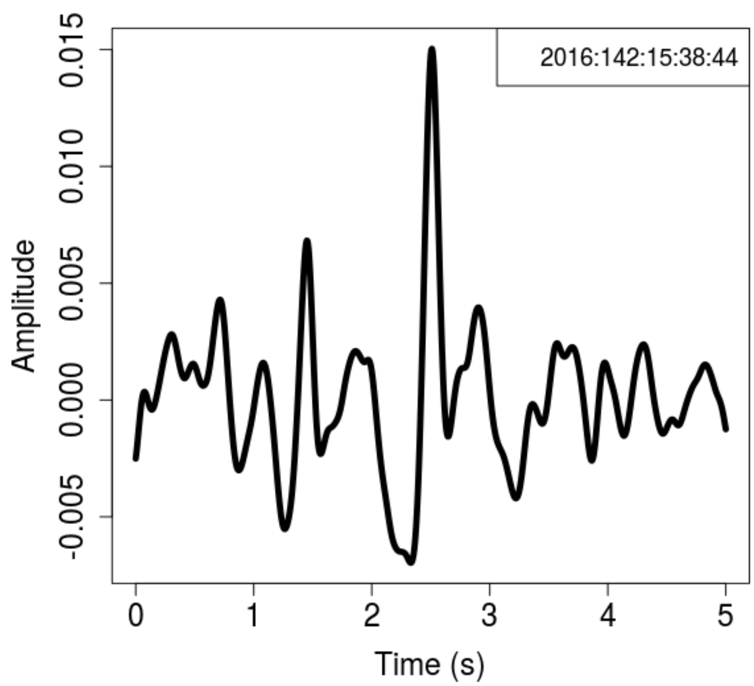
Amplitude
0
1
2
3
4
5
Time (s)

6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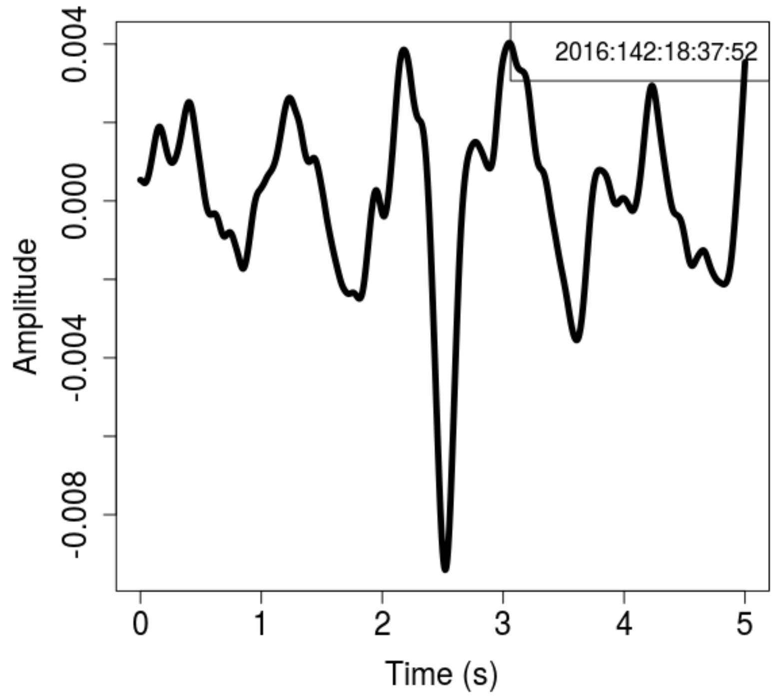
2
3
4
5
Time (s)

7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2
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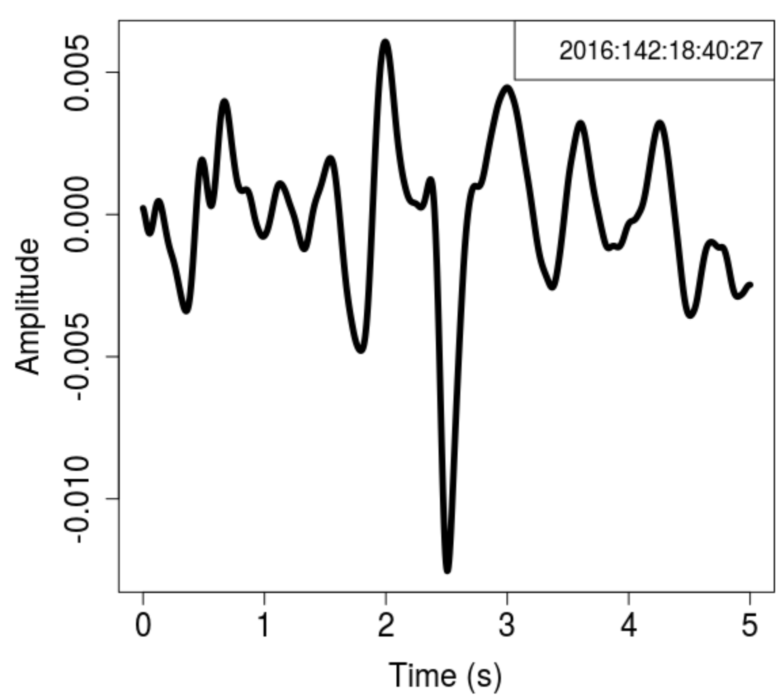
4
5
Time (s)

8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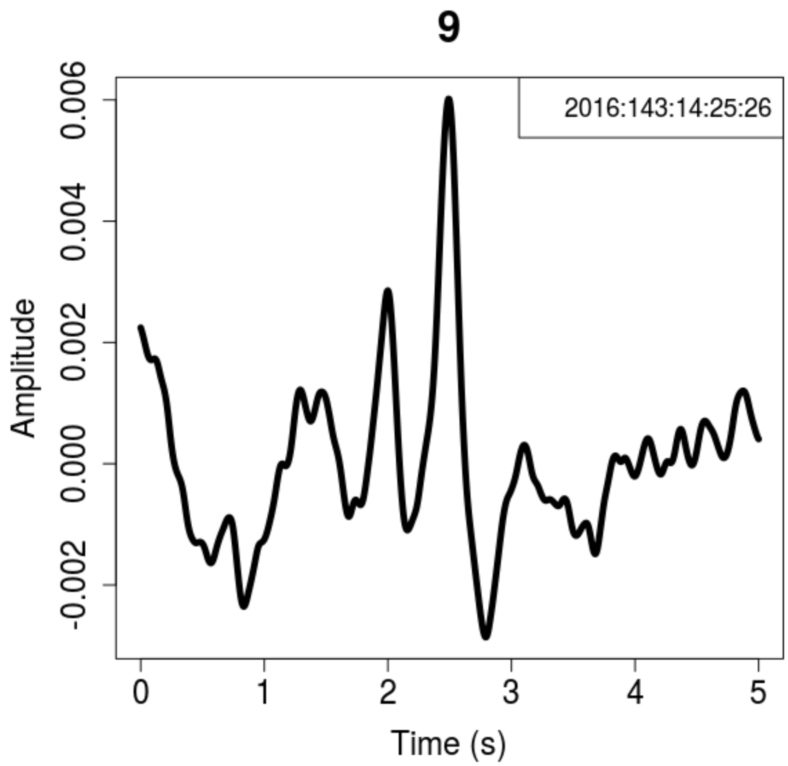
4
5
Time (s)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2
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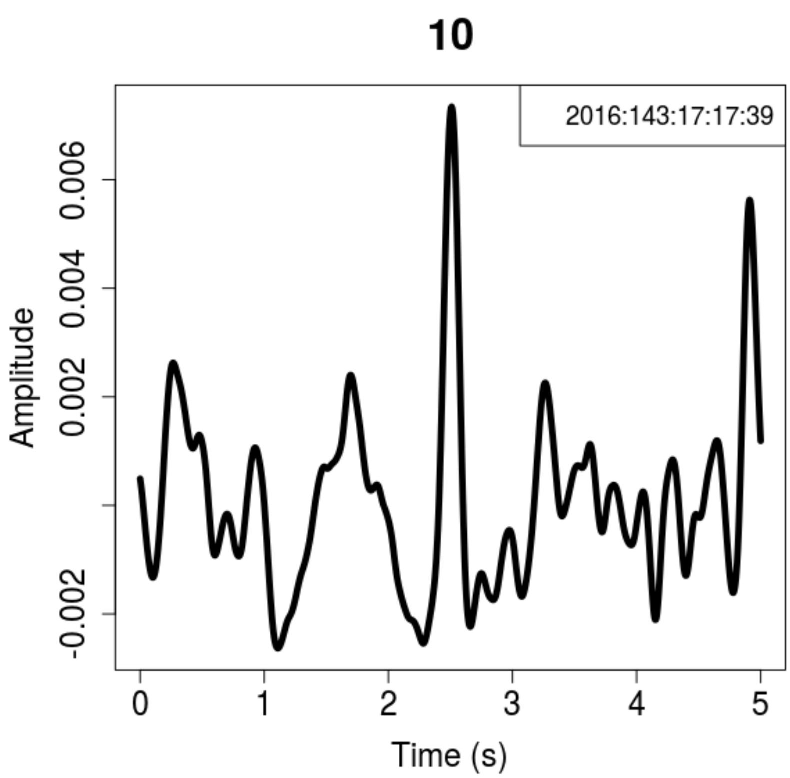
4
5
Time (s)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Time (s)

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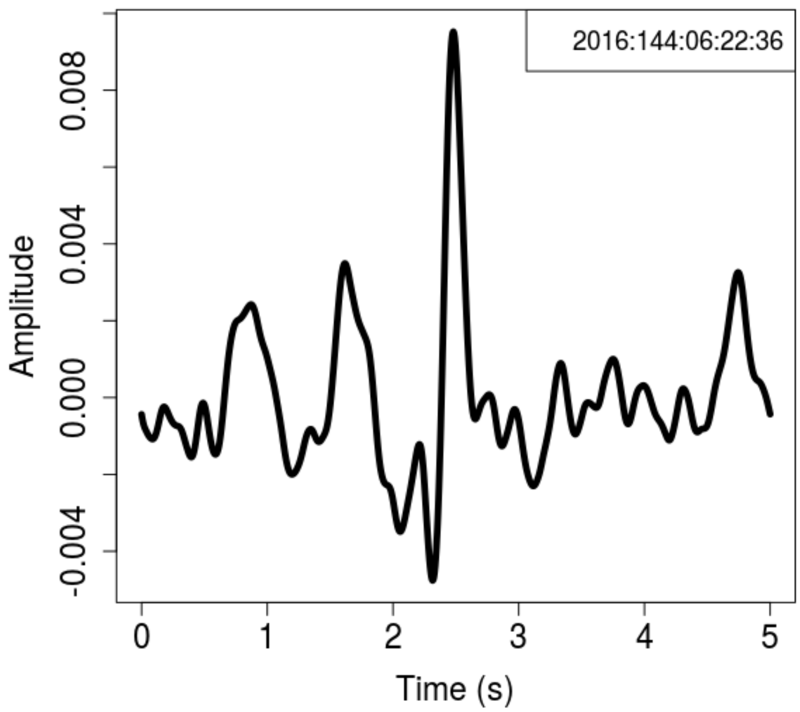
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Time (s)

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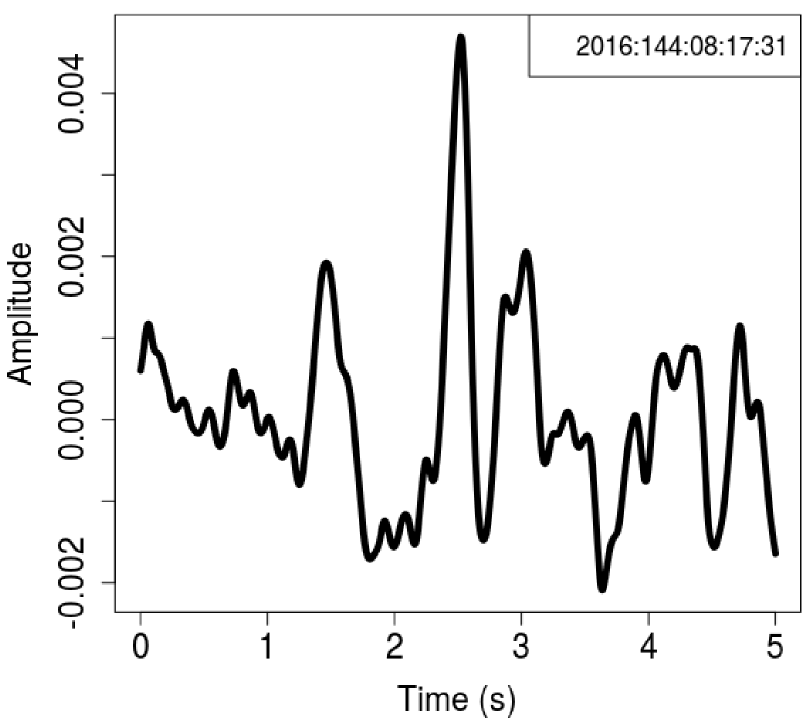
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Time (s)

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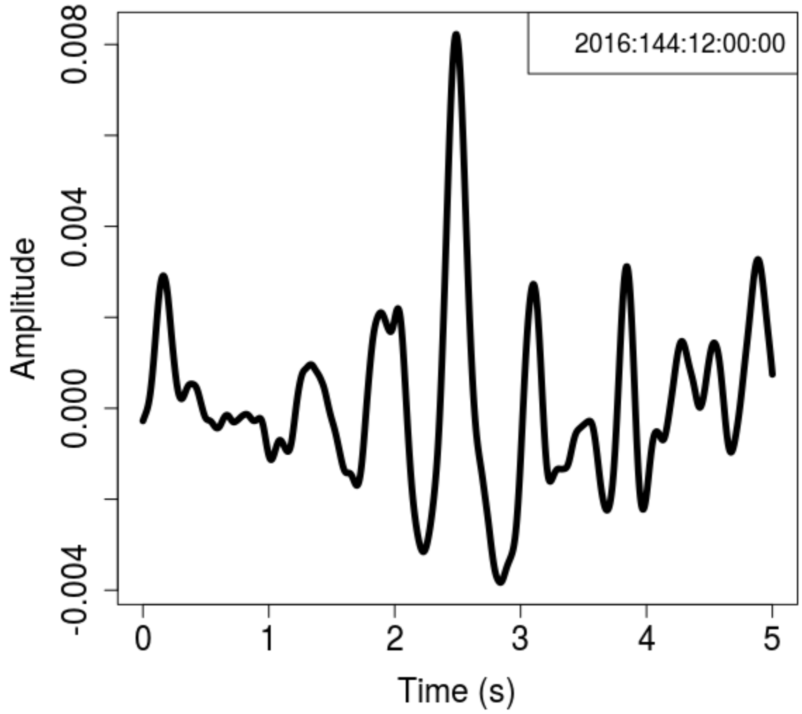
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Time (s)

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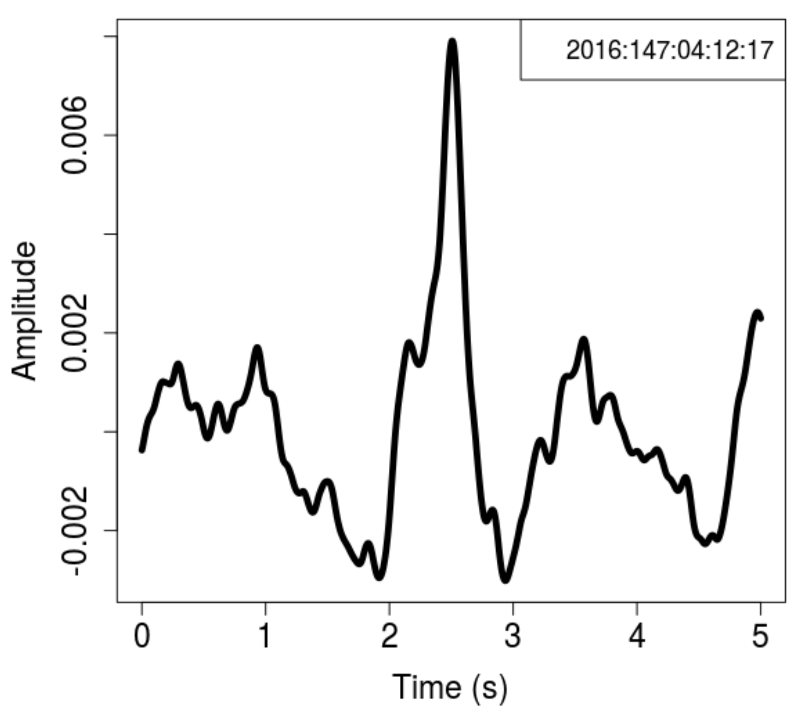
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5
Time (s)

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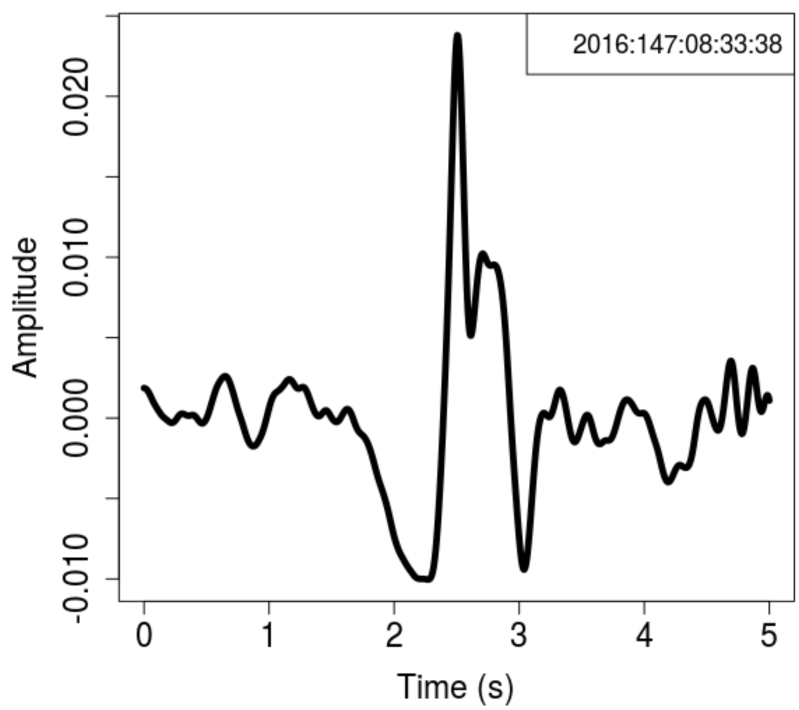
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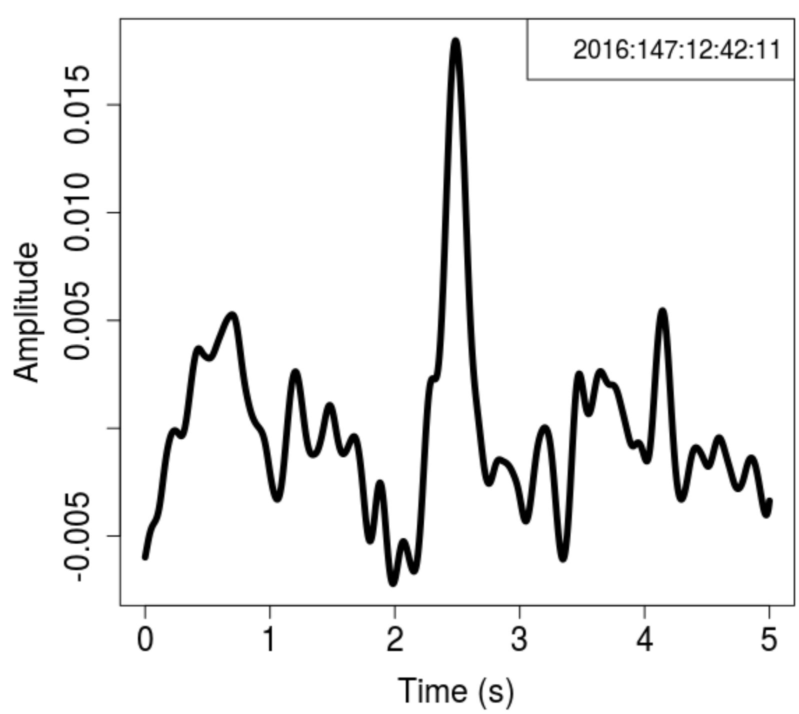
Time (s)

16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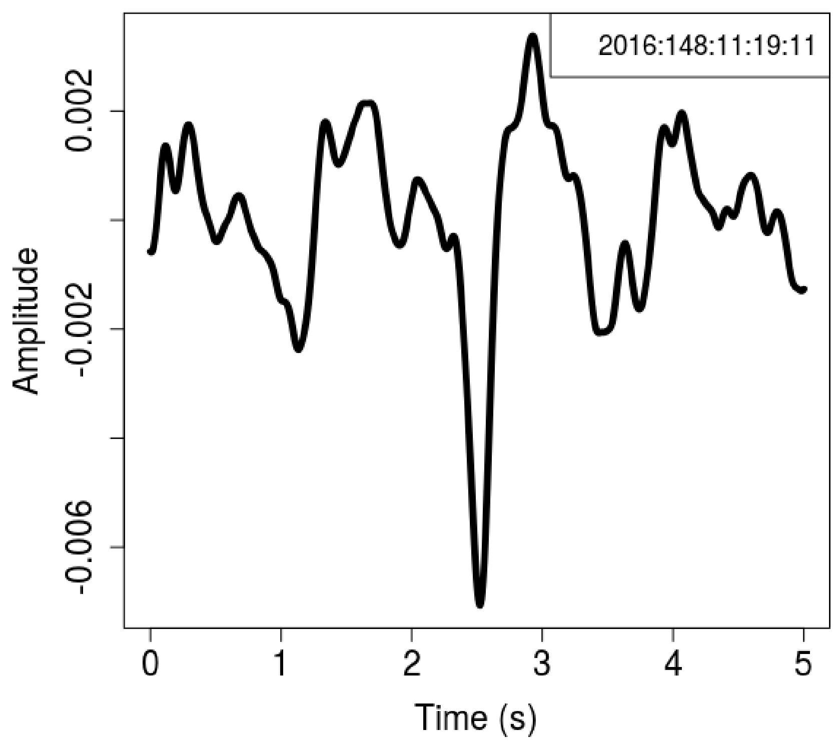
4
5
Time (s)

17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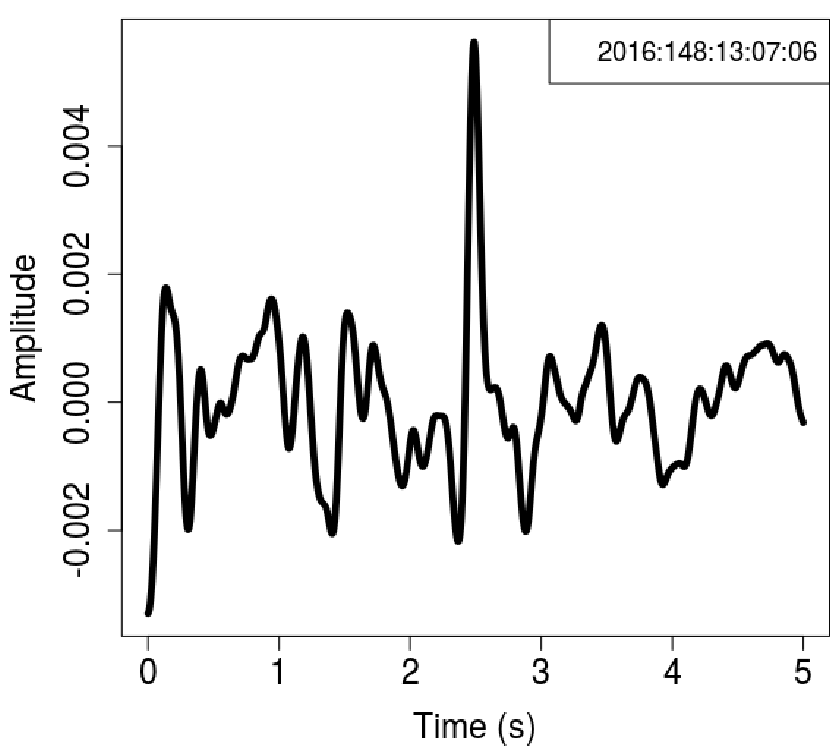
4
5
Time (s)

18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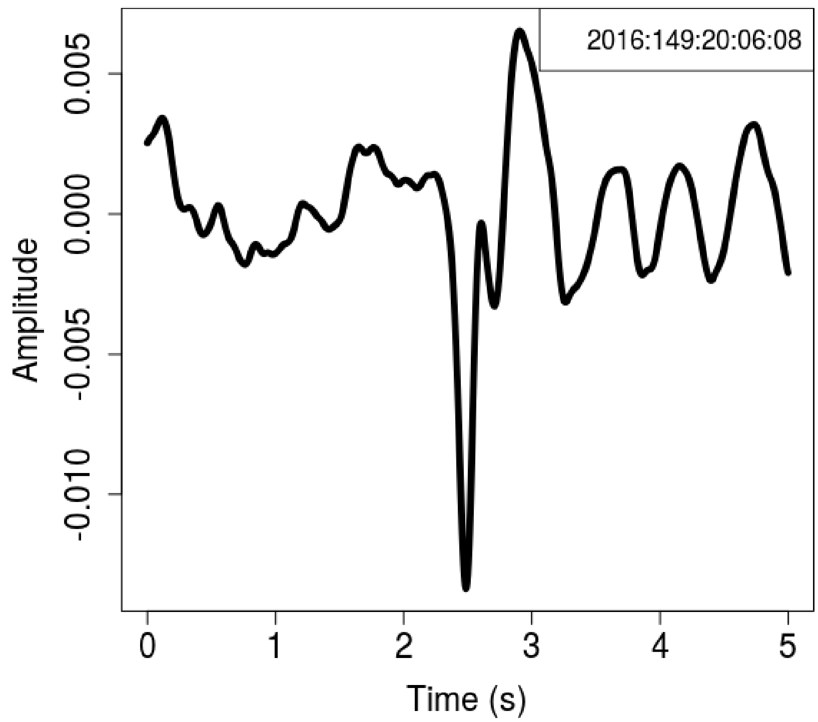
2
3
4
5
Time (s)

19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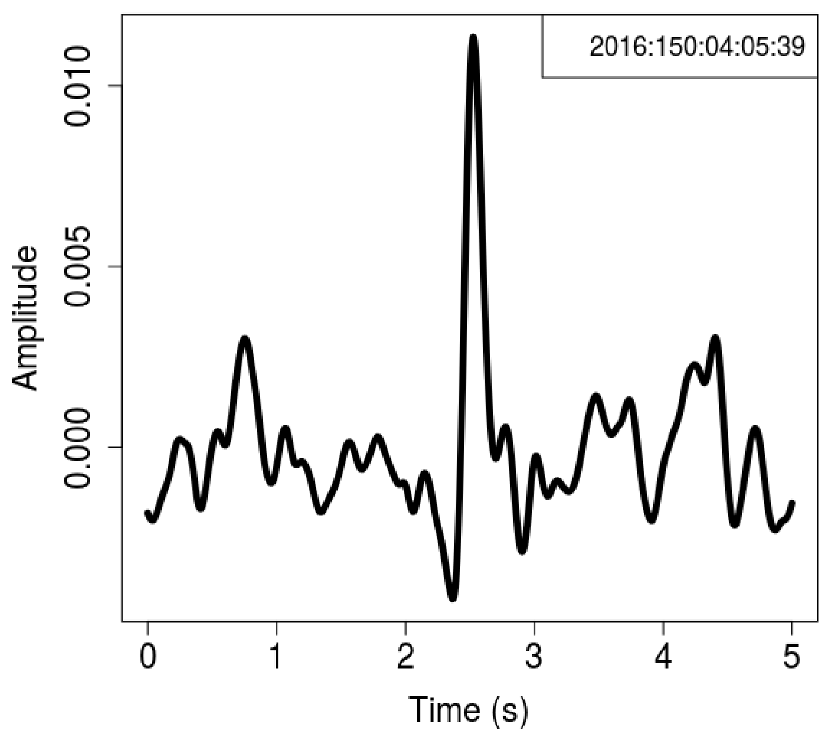
5
Time (s)

20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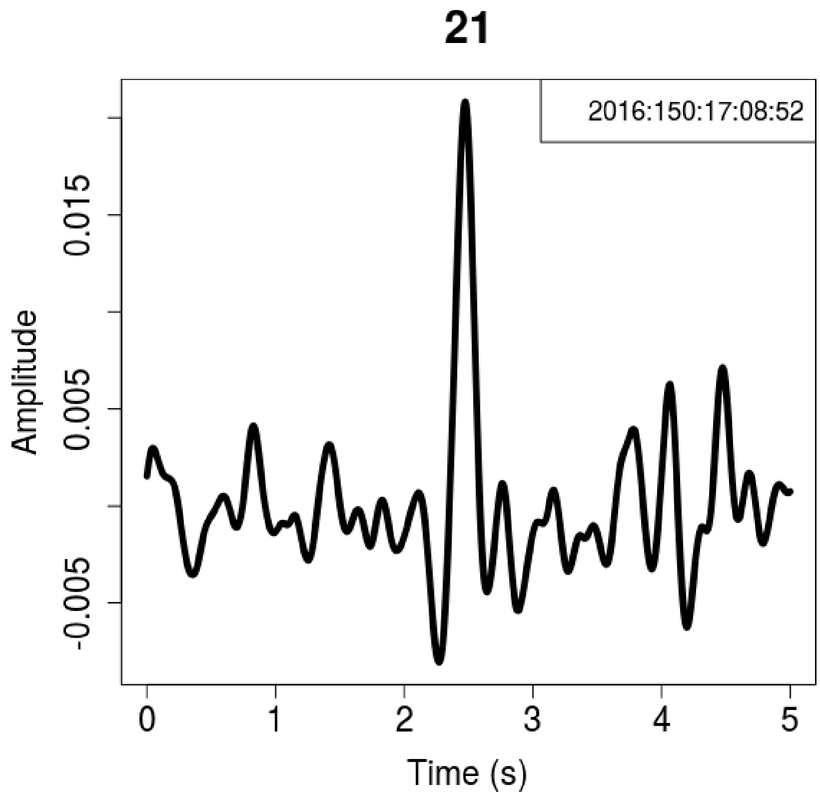
Time (s)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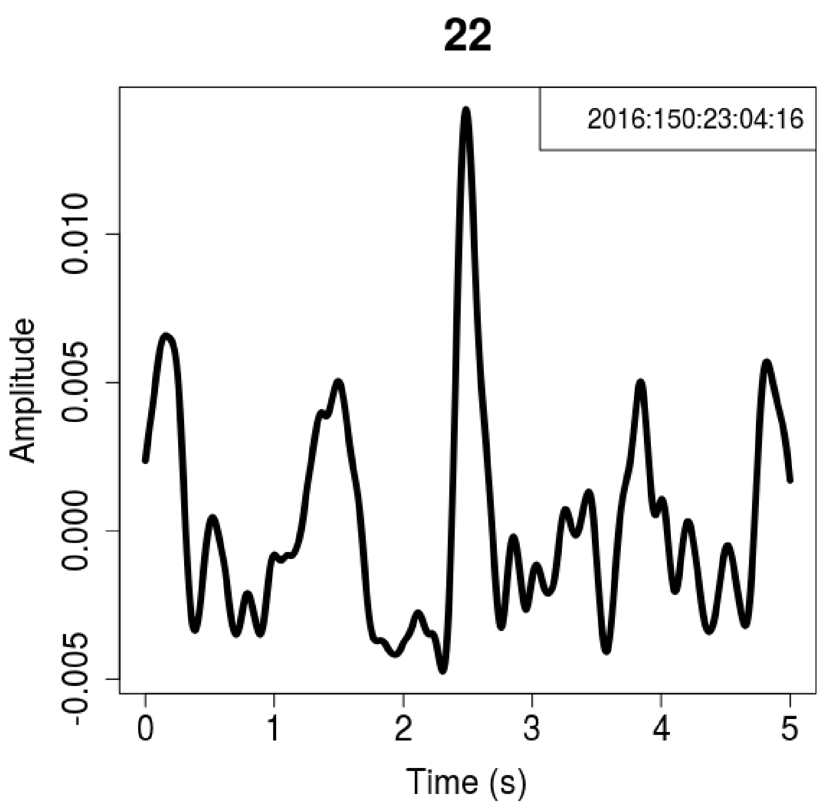
Time (s)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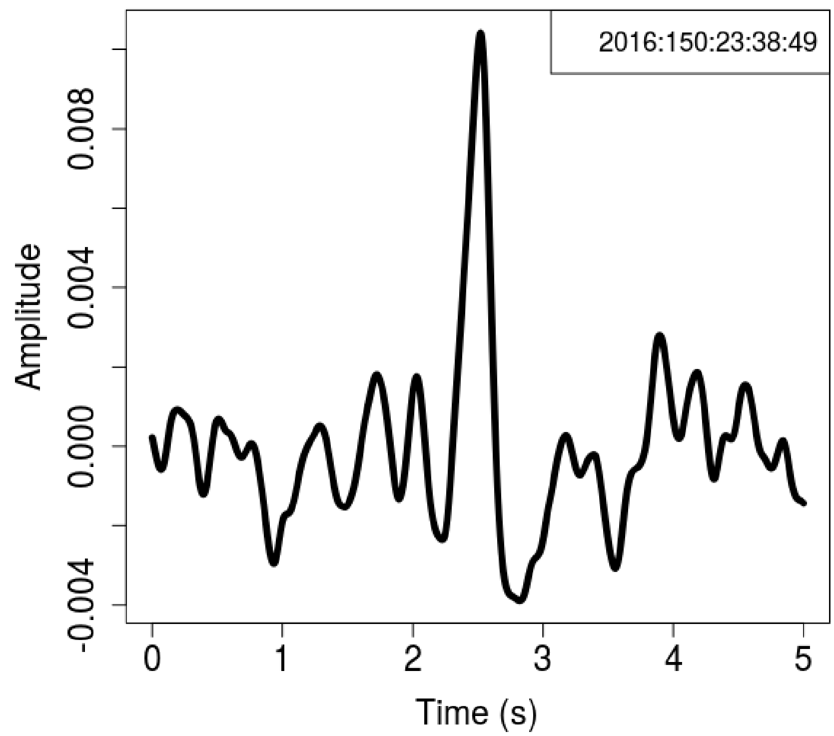
1
2
3
4
5
Time (s)

23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Amplitude
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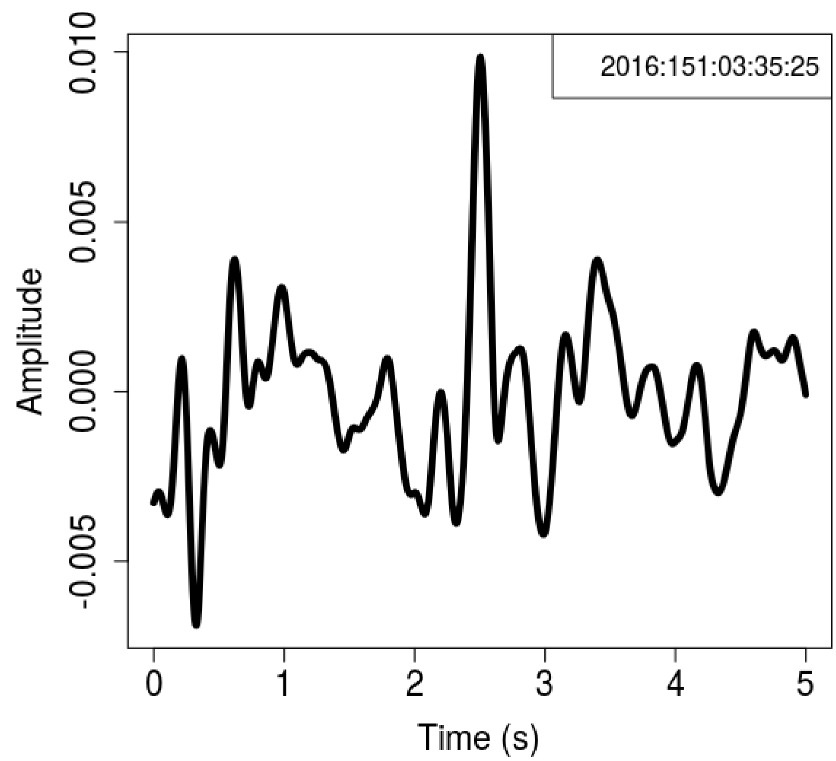
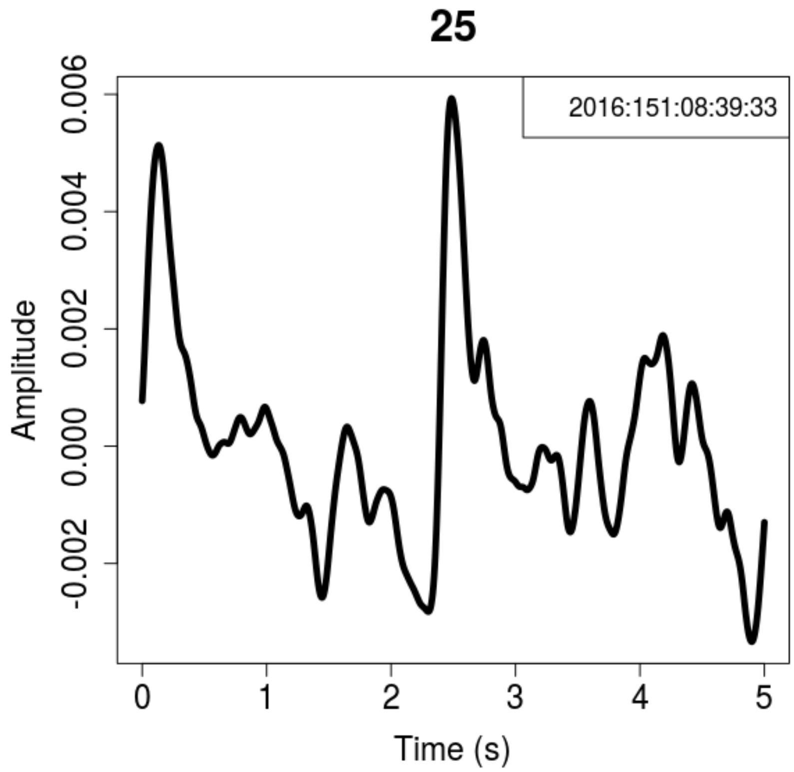
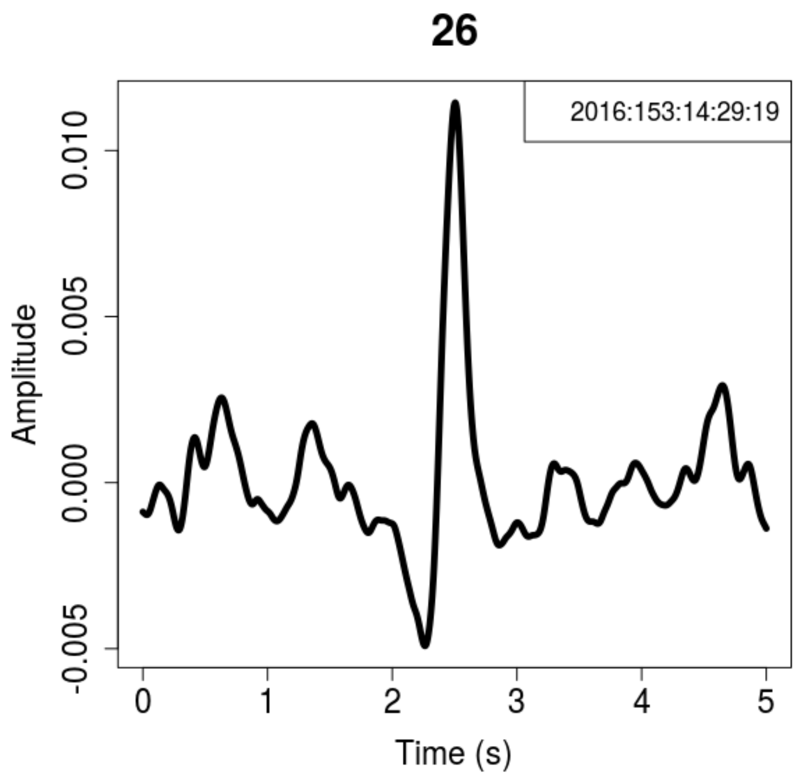
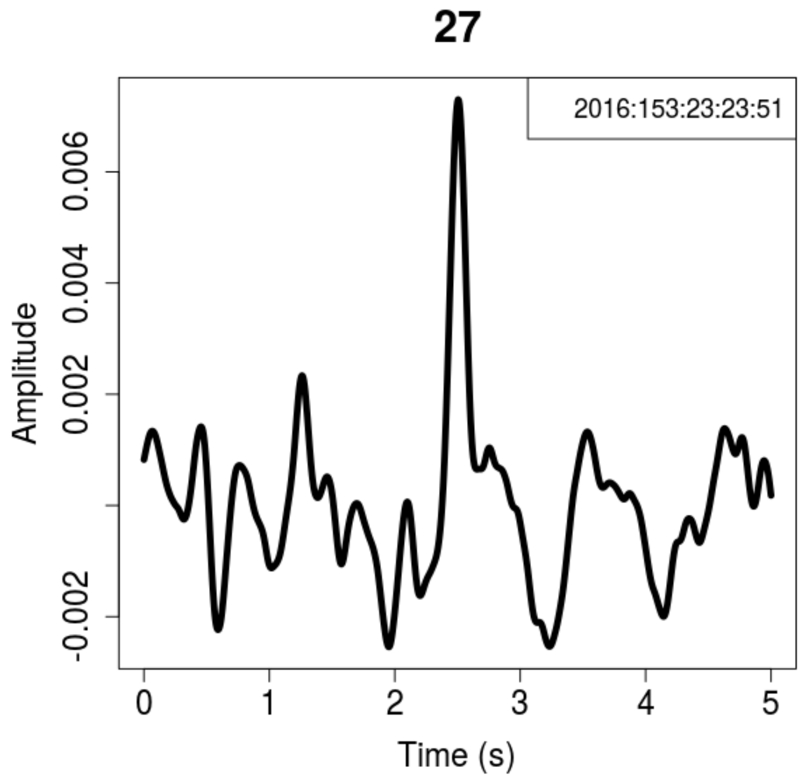
-0.004
0
1
2
3
4
5
Time (s)

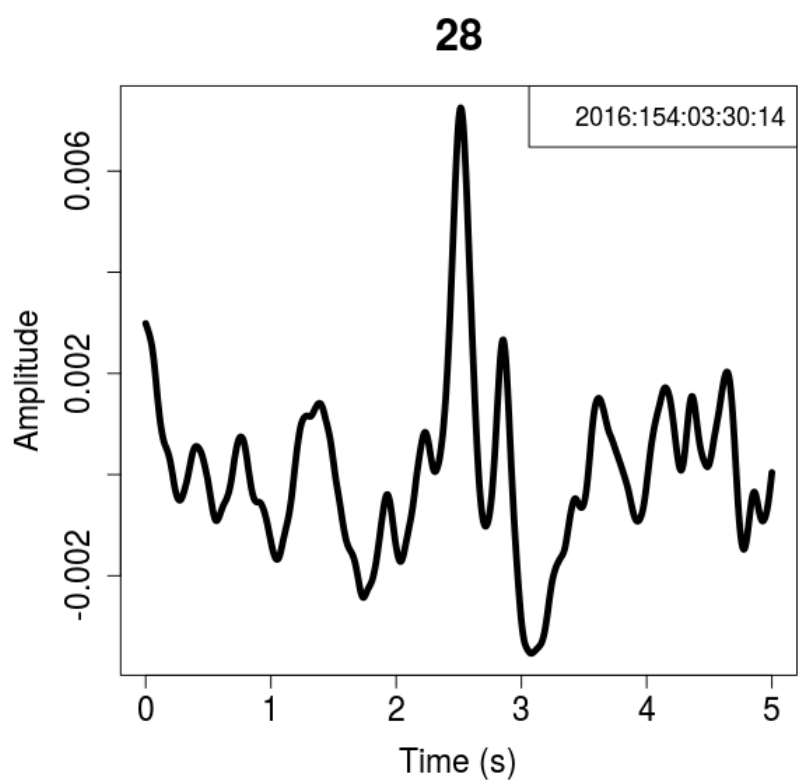
24

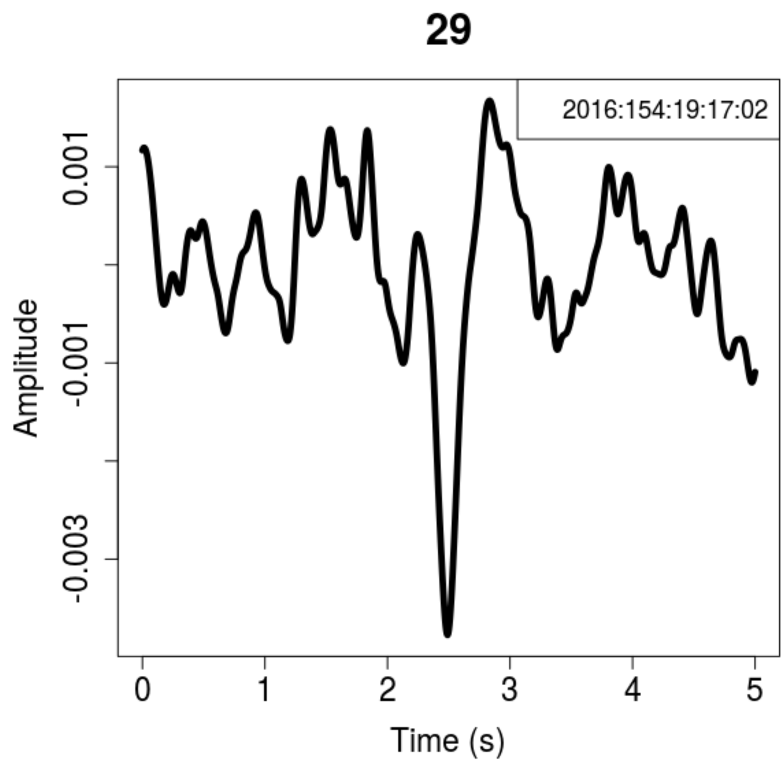

2016:151:03:35:25
Amplitude
0.010
0.005
0.000
-0.005
0
1
2
3
4
5
Time (s)


25
2016:151:08:39:33
Amplitude
0.006
0.004
0.002
0.000
-0.002
0
1
2
3
4
5
Time (s)


26
2016:153:14:29:19
Amplitude
0.010
0.005
0.000
-0.005
0
1
2
3
4
5
Time (s)


27
2016:153:23:23:51
Amplitude
0.006
0.004
0.002
-0.002
0
1
2
3
4
5
Time (s)


28
2016:154:03:30:14
Amplitude
0.006
0.002
-0.002
0
1
2
3
4
5
Time (s)


29
2016:154:19:17:02
0.001
-0.001
-0.003
Amplitude
0
1
2
3
4
5
Time (s)

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